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Study of the effect of ultrasonic vibrations on the color and turbidity of waters

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A STUDY OF THE EFFECT OF ULTRASONIC VIBRATIONS ON THE COLOR AND TURBIDITY OF WATERS

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by

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A Study of the Effect of Ultrasonic Vibrations on the Color and Turbidity of Waters

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ABSTRACT

The effects of intense ultrasonic irradiation on various samples of colored waters and turbid waters were studied at 400 Kc. Conclusions are that ultrasonic treatment at this frequency does not aid or cause color removal, and that a very small amount of turbidity can be removed, but not enough to be of practical importance.

INTRODUCTION

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Object:

The object of this thesis, as the title implies, is to study the effects of ultrasonic waves on colored and/or turbid waters, and to suggest possible engineering applications of these effects to water treatment practice.

Scope:

This investigation is limited to the study of the possible effects of ultrasonic waves on the removal of color and/or turbidity with or without the addition of floc-forming chemical additives.

It is beyond the scope of this thesis to investigate the bacteriological effects on the waters treated, although the literature of the field contains numerous references to the very destructive action of ultrasonic radiation on small living organisms. A study of the effects of ultrasonic radiation, with a coagulant other than alum, and with varied coagulant dosages is also beyond the scope of this thesis, but is certainly suggested for further work.

Importance:

The interest of the waterworks engineer is always in the greatest possible improvement of the clarity, for esthetic reasons, as well as sanitary quality of the effluent from his plant, within the limitations of the raw water available, the plant facilities available, and the funds available. In the efficient and economic accomplishment of

these results, the importance of any and every method of reducing the required size of mixing basins and sedimentation basins is not questioned. Proprietary chemical additives and various mechanical accelerators are all used to this end. Another ever present goal is to reduce the amount of coagulant used, since this may in some cases be one of the major items of operating expense. As adequate and inexpensive ultrasonic generators are developed in the years to come, and if methods of applying them are discovered, ultrasonic wave treatment may play its part in this field.

History:

Sound waves in the frequency range to which the human ear responds (about 16 cycles per second to 20,000 cycles per second) are arbitrarily called "audible". There is no fundamental physical difference between these and other frequencies. Those below this audible range are called "subsonics", and those above are called "supersonics" or "ultrasonics".

Several means of generating ultrasonic waves are available, each with its limitations as to frequency and intensity. Detailed descriptions of the various devices and the principles of their operation can be found in the excellent works of Bergmann, and of Sollner (see the chapter of Ultrasonics in the book Colloid Chemistry--Alexander) and only a brief listing will be given here.

1. Tuning Forks - As early as 1899, Konig demonstrated that ultrasonic waves may be produced in air with tuning forks,

up to frequencies of about 90 Kc., but the output is so damped, and the energy so small, that the waves have no practical use.

2. Galton Whistle - In 1900, Edelman designed the Galton Whistle which is operated by a stream of air flowing through a nozzle against a sharp circular knife edge setting the air in vibration. With care in its operation, vibrations of reasonable constant frequency and intensity can be obtained up to about 150 Kc.

3. Gas Current Generator - Based on an effect observed in 1890 by Mach and Salcher, Hartman in the early 1930's designed a Gas Current Generator which gives considerably higher energy outputs than obtainable with the above-mentioned Galton Whistle. If a current of air is allowed to stream through a nozzle at a speed greater than sound velocity (i.e. under a pressure of 0.9 atm. or more), a periodic structure of regions of high and low pressure is formed. The regions of high pressure, being intervals of instability in the jet, make possible the production of sound waves when a hollow body, serving as an oscillator, is brought into these regions of instability. Hydrogen may be used to give higher frequencies up to 500 Kc. Reasonable sound outputs are claimed for the equipment, and because of its simplicity and inexpensive apparatus, this type generator will undoubtedly become very useful in ultrasonics studies.

4. Magneto-strictive Generators - If a rod or tube of nickel, invar, or monel is brought into a magnetic field

parallel to its length, the length is changed slightly. This phenomenon is called the "magneto-strictive effect", and its application has given rise to the magnetostrictive generator. If an alternating magnetic field of the same frequency as the natural elastic period of the rod is caused to surround the rod, the intensity or amplitude of the oscillation will be a maximum, and sound waves of the same frequency will be sent out from the end of the rod. Higher frequencies may be obtained by exciting the rod with frequencies which are harmonics of the fundamental, but consequent loss of intensity is suffered. Very good sonic outputs can be obtained up to frequencies of about 60 Kc., and the equipment has a definite advantage of simplicity and inexpensiveness compared to the piezo-electric type. This magnetostrictive generator finds a very important use in the under water echo-ranging gear as used by the U.S. Navy and others.

5. Piezo-electric Generators - Certain crystals, notably quartz, tourmaline, and Rochelle salt, have the property of developing electric charges on definite crystal faces when subjected to pressure or tension, a phenomenon discovered by the Curie brothers in 1880. This effect was found to be reversible--i.e. if a correctly oriented crystal is brought into an electric field of force, the crystal is made to contract or expand in certain directions, the amount of contraction or expansion being directly proportional to the voltage applied to the crystal. Thus if this crystal is placed in an alternating electric field (which can be

produced by any one of a number of different designs of oscillating electric circuits) the crystal will expand and contract periodically, and the maximum amplitude will occur when the impressed alternating field has a frequency resonant with the natural frequency of the crystal, a factor dependent upon the crystal dimensions. Harmonic vibrations of higher frequency can be and are impressed but the conversion of electrical energy into sonic energy decreases in efficiency. This "reciprocal piezo-electric effect" is the principle of the piezo-electric ultrasonic generator, the type in most general use today, and the type used for this investigation. Powerful oscillations are possible, and the very highest frequencies have been obtained by this method--up to one billion cycles per second.

It bears mention here that to most effectively transmit these vibrations, it is required that a medium be used which has nearly the same specific gravity and sound velocity as the oscillating quartz. The medium most frequently used is transformer oil. It is evident by the same token, that air is a very poor medium and that energy outputs are extremely small.

Effects of Ultrasonic Waves and Present Theories:

Although commercial application of ultrasonic waves is very limited to date, much research is progressing at the present moment in an effort to discover new uses for the known effects of this important scientific tool. A great deal more theoretical work must be done before the mechanism of these peculiar effects can be fully explained, but the emulsifying, dispersing, and chemical effects are presently thought to be the result of cavitation, i.e. the formation and collapse of bubbles. A sound wave travelling through a liquid compresses it and stretches it periodically. If the stretch is moderate, and irradiated liquid is free of gas, nothing much happens; but if the liquid is saturated with gas, gas bubbles appear and subsequently collapse. Lord Rayleigh calculated the pressures which may occur when a vapor bubble collapses in a liquid and found them to be of the order of thousands of atmospheres locally. Such tremendous local stresses and concentrations of energy can naturally cause intense mechanical effects; and emulsification and dispersion are thought to be caused by violent hammering of the collapsing cavities occurring at the phase boundaries between liquid and solid. In carrying this theory farther to the oxidation effects, it is assumed that dissolved oxygen is activated at the liquid-gas interfaces by the collapse of the cavities. Intense local heating may also be a factor in this activation.

The theories as to the coagulating effects are

much too involved to argue here, but briefly Woods and Loomis believed that "radiation pressure" was responsible for the coagulation of visible particles, while Sollner and Bondy explain it by a migrating process. There are indications in the case of truly colloidal solutions, that the mechanism may be the result of electrical forces, but apparently no satisfactory theory has yet been developed by the colloid chemists.

Among the many phenomena observed by a score of investigators in recent years and recorded in the literature are the following, some of which may have a relation to the field of water treatment; and others which may have no immediate relation, but which may provoke thought as to their action for an idea that could be related:

1. The prevention of grain formation and other improvements during the preparation of photographic emulsions.
2. The reversible liquefaction of thixotropic gels--e.g. Ferric Oxide, Bentonite, and Aluminum Hydroxide.
3. The peptizing of hydrated precipitates--e.g. those of ferric, chromic and aluminum hydroxides.
4. The coagulation of aerosols (suspensions of a fine solid or liquid in air or a gas) This effect is being put to industrial use in the precipitation of smoke.
5. The orientation of mica, glass, and quartz particles in liquids.
6. The emulsification of immiscible liquids. A patent exists for the homogenization of milk by this means. Many

other possible applications might be thought of for this phenomenon.

7. The dispersion of solids in liquids. This has particular use with pigments and dye stuffs.

8. The reducing of the viscosity of colloidal solutions.

9. The flocculation and deflocculation of some suspended particles in liquids.

10. The cleaving of highly polymerized molecules--e.g. starch, gum arabic, gelatin, etc.

11. The activation of oxidation of some solutions such as KI, $NaHSO_4$, NaCl, and of organic halogens.

12. The reduction of dilute $KMnO_4$ solutions.

13. The decoloring and changing of the color of some indicators and dyes--e.g. BromThymol Blue, Brom Phenol Blue, Phenolphthalein and others.

14. The degassing of metal melts.

15. The lowering of the boiling point of some liquids.

16. The marked destruction of cells in biological experiments. The effect of ultrasonic radiation on B. Coli is still in argument, but at least one claim has been made for use of ultrasonics to reduce the Total Bacteria Count of milk.

EXPERIMENTAL PROCEDURE

EXPERIMENTAL PROCEDURE

General Outline of the Problem

From a review of the many reports of investigators of the physical, chemical, and biological effects of ultrasonics, the possible widespread application of their use industrially, and as a research tool, is evident. However a search of the available literature has failed to reveal their use in any present water treatment practice. Therefore it was thought interesting and advisable to make a study, within limits, of the possible applications of these new phenomena to water treatment, drawing upon the fund of observed effects listed earlier in this paper and in the bibliography.

First, noting that the acceleration of certain oxidation reactions, both organic and inorganic, had been observed, it was decided to subject samples of various colored waters to irradiation to see whether the compounds causing that color might be oxidized. It will be recalled that aeration itself, with its presumed oxidation, is sometimes used as an aid to color removal in present practice. Therefore it seemed of consequence to begin the study with this phase.

Secondly, the coagulating effects of ultrasonic waves on a number of solid-liquid, solid-gas, liquid-gas, and liquid-liquid systems has been frequently mentioned. Likewise it seemed worthwhile to study the effects of

radiation on various samples of turbid waters.

In the third phase of the work, it was decided to make a study of the effects on samples of both colored and turbid waters, first irradiated, then given coagulation treatment. This part of the investigation was based on the presumption that the intense concentrations of energy which occur at tiny local points in the sample, as explained in the cavitation theory previously, might have some effect on the electrical nature or other physical characteristics of the particles causing turbidity, or upon the fine electrically charged suspensoid particles believed to be the cause of color in natural waters.

One other suggestion of a subject for investigation was the possible action of radiation on floc particles themselves. This phase of the work was abandoned in view of the literature references to peptization of some metal hydroxide precipitates, and a few rough preliminary experiments which also demonstrated that the radiation, together with the convection currents accompanying it dispersed floc formation rather than aiding it.

Discussion of Variables

The prime variable to be controlled in ultrasonic irradiations is the amount of sound energy reaching the sample. It would be desirable that all investigative papers on this subject include a reference to the actual intensity of this energy in absolute units received by a sample. Unfortunately, this reference is always omitted in such papers for the reason that as yet there is no simple, reliable method for measuring these values. Several attempts at calorimetric measurement of the energy transmitted from the vibrating crystal to the oil bath were made early in this study, but later references in the literature point out the many gross errors involved in trying to estimate the amount of sonic energy from these data.

The next best thing to knowing the absolute amount of energy received by a sample is to know that that energy input is kept constant for a series of runs. Factors which might affect the amount of energy received are the following:

1. The type of reaction vessel (shape, size, wall thickness)
2. Distance between the reaction vessel and the crystal;
3. Depth of oil in the bath (oil absorbs the energy);
4. Operating voltage of the generator;
5. Current in the resonant circuit containing the quartz crystal;
6. Time of irradiation.

In an effort to establish the reproducibility of

the sonic output, preliminary control runs were made in which dilute solutions of standard potassium iodide were irradiated and the free iodine liberated titrated with standard sodium thiosulfate. It was felt that if it could be shown that a definite amount of oxidation (or, more exactly, a definite acceleration of oxidation) could be promoted with the above factors held constant, then it might be reasonably assumed that the same amount of sonic energy would reach the samples in all runs. Evidence to support this contention is presented in the data in Table I.

Another variable which might well be expected to influence any results is the pH of the sample. For this reason, all runs were tried at acid, neutral, and alkaline pH.

In the coagulation phase of the experiments, not only the dosage, but also the temperature, pH, and time and degree of mixing are variables. With this is mind, all coagulations were run at room temperature, which remained fairly constant throughout the series. Time of mixing was controlled as well as the violence of agitation, although it was difficult to maintain the stirrers at a constant speed.

Off hand, onemight expect that the frequency of the vibrations would vary, but actually the output of the generator was quite stable in this respect. Checks made with a frequency meter indicated a change of less than one fortieth of one percent. Furthermore, references indicate

that frequency variations over a range of even several hundred kilocycles do not give different results.

General Conditions for all Runs

From previous considerations, the following conditions were adopted as constant for all runs:

1. All irradiations were performed for a period of twenty minutes.
2. After tuning the apparatus to the resonant frequency of the quartz crystal, a dial setting of the main variac of 35 was used throughout. (Although this did not give the maximum power output, it was chosen because it maintained conditions at a point well below that at which the protective relays would ever function during a run and cut out the power supply.)
3. The reaction vessel was always a 150 ml. Erlenmeyer flask, set with its bottom parallel to the crystal face and one inch above it.
4. The oil bath in which the vibrating crystal was immersed consisted of a cylindrical glass jar, 12 inches in diameter, filled with clear transformer oil to a depth of $5\frac{1}{2}$ inches, which placed the surface $1\frac{1}{2}$ inches above the crystal mount.

Alum and lime doses were arrived at by trial and error, the minimum dosage which gave a good appearing floc being used for the run.

Many of the chemical effects of ultrasonic treatment have entailed oxidation reactions, with the intermediate formation of H_2O_2, HNO_2, and HNO_3. In this connection it has been pointed out that the amount of dissolved oxygen in the samples might have a definite bearing

on the extent of oxidation reactions. For this reason, all samples were vigorously shaken for several minutes before adjustment of pH to insure having approximately the same amount of dissolved oxygen in each run.

Methods Used for Specific Runs

(For Composition and Preparation of Samples See Section on Equipment and Materials)

Plain Color Runs:

After shaking the sample of colored water, a 600 ml. portion was poured out and the pH adjusted to the desired value for the run (dilute sulphuric acid being used to obtain low pH and dilute lime water to obtain high pH). Values of pH were determined with the Hellige Comparator, while color was read by comparison with the regular potassium chloroplatinate color standards. Three 100 ml. portions were then drawn off and each irradiated for the prescribed twenty minutes, after which all three were mixed together, cooled to room temperature, and the color and pH again determined.

Color with Coagulant:

Sample preparation and irradiation procedure were exactly the same as for plain color runs. Two alum doses of the desired quantity were weighed out, and one placed in each of two coagulating jars. Two hundred and fifty ml. of the blank sample (not irradiated) were poured into one jar over the alum, the jar shaken vigorously for a moment, and then the contents stirred very slowly for ten minutes. After the stirring, the solution was allowed to stand quietly for ten minutes. Then the supernatant liquor was filtered off through coarse-grade laboratory filter paper and the color and pH determined. The same procedure was

followed with the irradiated sample, care being taken to lower the sample to room temperature before coagulation.

Plain Turbidity Runs:

Procedure was quite similar to that of the plain color runs: the large sample bottle was first shaken, after which 600 ml. was poured out and the pH adjusted. Turbidity was observed with the Hellige Turbidimeter, calibrated to read turbidity in terms of ppm SiO_2. (Unless specifically noted to the contrary, filtration of the sample through coarse grade laboratory filter paper preceded each reading of the turbidimeter.)

One hundred ml. portions were poured into the three reaction vessels, and were then irradiated for the twenty minute period. After allowing the samples to cool to room temperature, the turbidity and pH were again determined.

Turbidity with Coagulant:

This procedure was exactly the same as that used in the color with coagulant runs, except that turbidity was read instead of color.

Description of Generator

General:

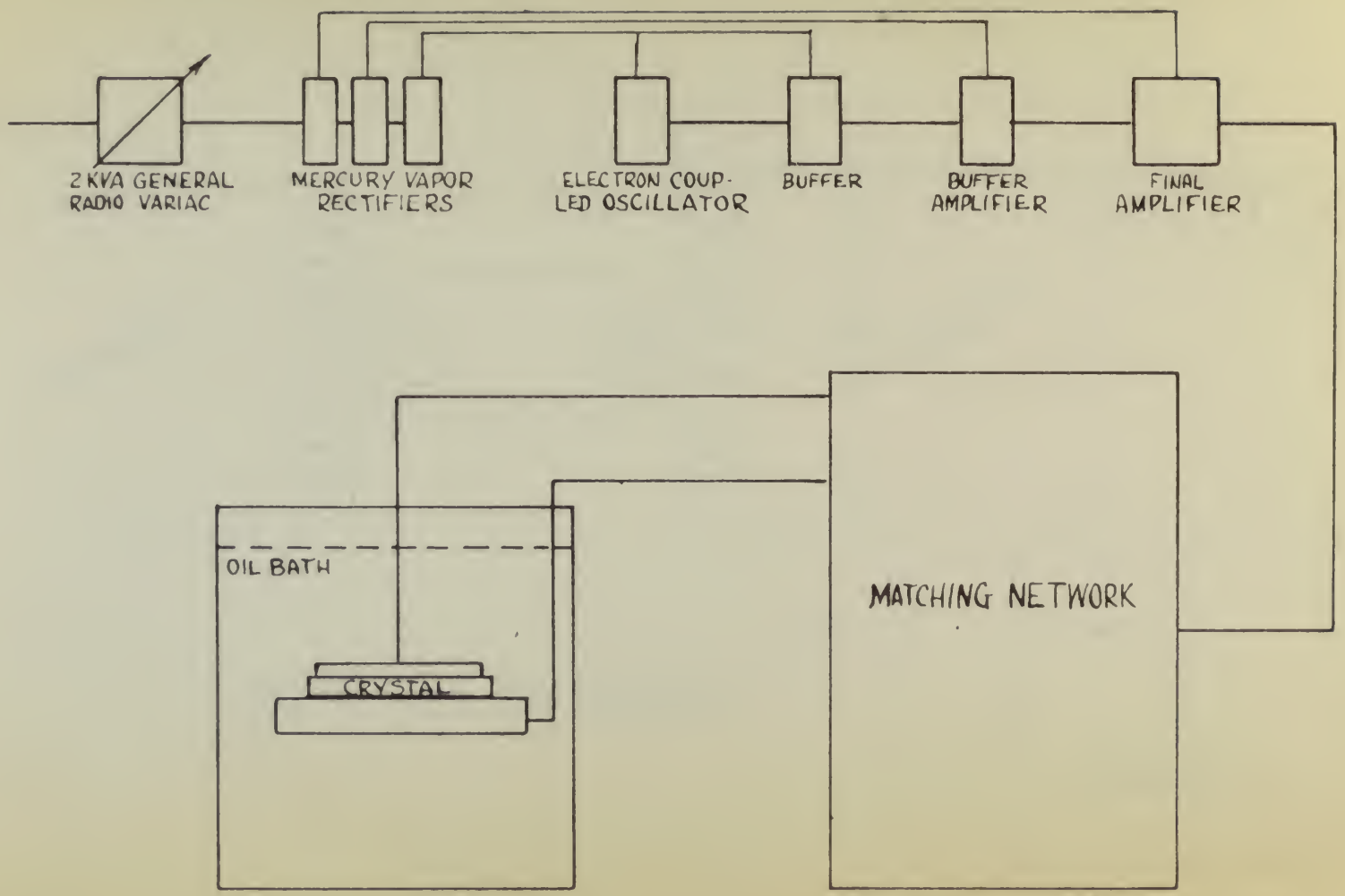
The ultrasonic generator used for this work is a 1000 watt unit employing the piezo-electric principle designed and built by Frederick W. Schremp as part of the thesis requirements for a B.S. in Chemistry at R.P.I. in 1942, and has been operated essentially in the form as designed by him. The outfit was planned to cover the approximate frequency range from 200 kc. to 800 kc. With the present setup, however, satisfactory operation has been obtained only with the 400 kc. and 510 kc. crystals, the former giving the visibly better output. However, this range can undoubtedly be extended by changes of the circuit elements in the matching network.

In the generator, an alternating voltage of the same frequency as the resonant frequency of the quartz crystal is produced. These oscillations are amplified in several stages, and the output is fed into a matching network which couples the piezo-electric quartz crystal circuit for maximum transfer of energy. When this high frequency voltage is applied to the faces of the crystal, the crystal expands and contracts in thickness, thus transmitting sound waves of the same frequency to the oil bath in which it is immersed.

The oil bath has two functions: First, it transmits the ultrasonic vibrations to whatever reaction vessel is being used. Second, it has excellent dielectric

properties, and greatly reduces the possibility of arcing between the upper and lower electrodes at the crystal faces, even though a drop of several kilovolts exists.

Diagrammatic Sketches of the generator and matching network layouts are included on the following pages to aid in the ensuing description.


2 KVA GENERAL RADIO VARIAC
MERCURY VAPOR RECTIFIERS
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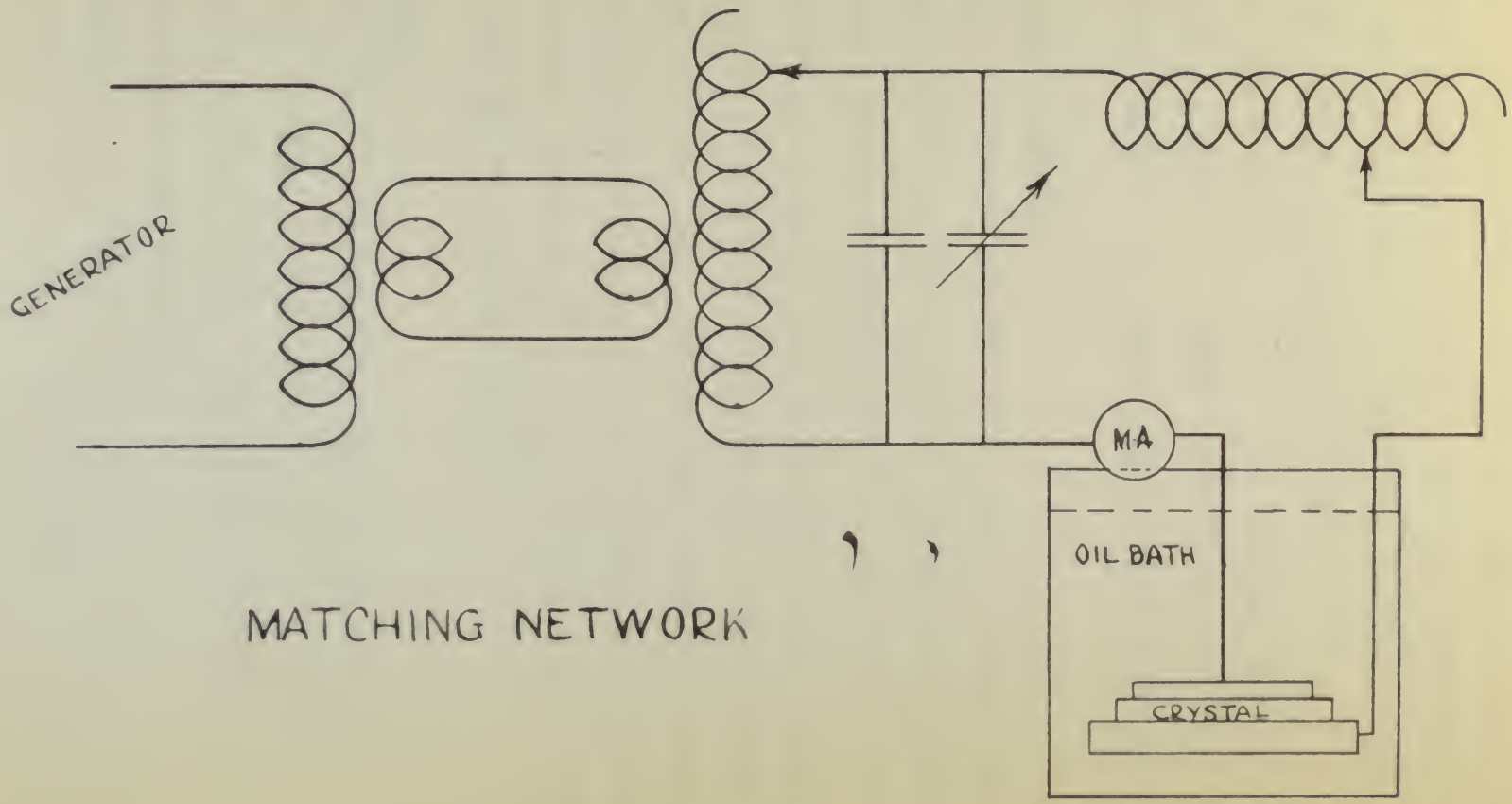

MATCHING NETWORK

Power Supplies:

Power for operation of the equipment is obtained from the standard 110V A.C. supply. Suitable transformers and mercury vapor rectifiers are employed to give direct current of the proper characteristics for:

Exciter supply - 600 - 700 volts @ 225 ma.

Buffer supply - 1000 -1250 volts @ 500 ma.

Final supply - 2000 -2500 volts @ 500 ma.

Radio Frequency Exciter:

Initial source of radio frequency voltage which is ultimately applied to the faces of the quartz crystal is an electron coupled oscillator. The requirements of this oscillator are, first, that its operation be stable, so that constant frequency vibrations will be maintained during a specific run, and, second, that it be flexible, in order to operate successfully over a range of frequencies. These requirements are met by the use of an electron coupled oscillator, the 6F6 and the buffer 807.

Amplification:

As shown in the sketch, the exciter unit is capacitatively coupled to the buffer amplifier circuit, which employs a Taylor TW-75. Ammeters are included in both the grid and plate circuits.

Output of the first amplifier excites the final amplifier stage by means of a link coupling to the grids of a pair of Taylor 822's. The output of this stage is

approximately 1000 watts. As in the original amplification stage, ammeters are included in the grid and plate circuits.

Protective Devices:

Reasonable and adequate protection is provided to safeguard the equipment in case of overload arising from misadjustment or shifting out of resonance. Overload relays are located in the cathode bias systems of the TW-75 circuit and that of the final amplifier. When the plate current exceeds a safe value, the 110V input to the plate transformer of that stage is cut out. In the original design of the equipment it was not considered necessary to furnish this same protection to the exciter stage, and no trouble has arisen due to the omission.

In addition, the main line has a double fuse block in series with both sides of the 110V input. The operator is prevented from accidental contact with high voltage inside the equipment by means of an interlock switch in the line input circuit which is so arranged that it is necessary to have the door closed and latched in order to start the generator. For servicing the apparatus, it is possible to deliberately clamp the switch closed.

Auxiliary Equipment and Materials

Equipment:

1. Hellige Turbidimeter
2. Hellige Comparator, for determining pH
3. Rack of 50 ml. Nessler tubes with potassium chloroplatinate color standards
4. Multiple, adjustable speed stirrer.

Materials:

1. Color samples
    a. Leaves were allowed to sit in a jar of water for approximately one month, after which the liquor was drawn off and mixed with Troy tap water to give the desired color.
    b. Hudson River water taken directly from the river at Green Island.
    c. Ground water from a swamp near Grafton, N.Y.
2. Color standards were made up by mixing enough of a 500 ppm stock sample with the proper amount of distilled water to give the desired color.
3. Turbidity samples:
    a. Silica suspension was formed by mixing 40 grams of powdered, 200 mesh silica with a litre of distilled water. After allowing the mixture to sit overnight the supernatant liquid with its suspended silica was drawn

off and diluted with distilled water until a turbidity of approximately 100 ppm was obtained.

b. Clay suspension was formed by grinding up the dried clay as much as possible, and then repeating the procedure for the silica suspension.

RESULTS AND CONCLUSIONS

DATA, TABLE I

Irradiation of KI Solution

Dilute KI Solution (.017N) Irradiated for varying periods of time. - 400 Kc. frequency - Variac Dial @ 20 Free Iodine liberated by the oxidation was titrated with Sodium Thiosulfate solution.

Time of Irradiation	ml. Thiosulfate Required	% Oxidation
5 Min	0.14	0.48%
10 Min	0.28	0.96%
15 Min	0.42	1.45%
20 Min	0.55	1.90%
25 Min	0.39	1.35%

DATA, TABLE II

Plain Irradiation of Colored Waters

Source of Sample	Before Irradiation		After Irradiation	
	pH	Color, ppm	pH	Color, ppm
Leaf Liquor	6.2	80	6.2	90
	7.0	80	7.0	80
	8.8	80	8.8	90
Hudson River	5.6	40	6.3	40
	7.2	40	7.7	40
	8.0	40	8.0	40
Grafton Swamp	6.4	200	7.3	200
	7.0	200	7.6	200
	8.2	200	8.2	200

LEAF LIQUOR SAMPLE

Alum Dose: 6 gr/gal
Coagulating Temperature: 25° C.

Sample	Before Irradiation		After Irradiation and /or Before Coagulation		After Coagulation	
	pH	Color ppm	pH	Color, ppm	pH	Color, ppm
Irradiated	6.2	80	6.2	90	5.6	50
Blank	- -	--	6.2	80	5.6	50
Irradiated	7.0	80	7.0	80	5.8	30
Blank	- -	--	7.0	80	5.6	30
Irradiated	9.1	80	9.1	80	5.9	25
Blank	- -	--	9.1	80	6.2	20

DATA, TABLE III

Coagulation of Colored Waters Preceded by Irradiation

DATA TABLE IV

Coagulation of Colored Waters Preceded by Irradiation

HUDSON RIVER SAMPLE

Alum Dose: 1.5 gr./gal.
Coagulating Temperature: 26° C.

Sample	Before Irradiation		After Irradiation and /or Before Coagulation		After Coagulation	
	pH	Color, ppm	pH	Color, ppm	pH	Color, ppm
Irradiated	5.6	40	6.3	40	5.3	5
Blank	- -	--	5.6	40	5.3	15
Irradiated	7.2	40	7.7	40	7.0	15
Blank	- -	--	7.2	40	6.9	15
Irradiated	8.0	40	8.0	40	7.1	15
Blank	- -	--	8.0	40	7.1	15

DATA, TABLE V

Coagulation of Colored Waters Preceded by Irradiation

GRAFTON SWAMP WATER

Alum Dose: 1.5 gr./gal.
Coagulating Temperature: 23° C.

Sample	Before Irradiation		After Irradiation and /or Before Coagulation		After Coagulation	
	pH	Color, ppm	pH	Color, ppm	pH	Color, ppm
Irradiated	6.4	200	7.3	200	6.2	50
Blank	- -	--	6.4	200	6.0	40
Irradiated	7.0	200	7.6	200	6.0	50
Blank	- -	--	7.0	200	6.3	55
Irradiated	8.1	200	8.1	200	6.5	65
Blank	- -	--	8.2	200	6.7	60

DATA, TABLE VI

Plain Irradiation of Turbid Waters

Sample	Before Irradiation		After Irradiation	
	pH	Turbidity, ppm	pH	Turbidity, ppm
Silica Suspension	4.2	100	4.2	90
	6.7	100	6.7	75
	8.6	100	8.9	85
Clay Suspension	4.6	100	5.3	110
	7.3	100	7.8	85
	9.1	100	9.1	105

DATA, TABLE VII

Turbidity Runs With Coagulation

SILICA SUSPENSION

Alum Dose: 6 gr./gal.
Lime Dose: 4 gr./gal
Coagulating Temperature: 25° C.

Sample	Before Irradiation		After Irradiation and /or Before Coagulation		After Coagulation	
	pH	Turbidity, ppm	pH	Turbidity, ppm	pH	Turbidity, ppm
Irradiated	4.2	100	4.2	90	7.8	2
Blank	- -	—	4.2	100	8.4	6
Irradiated	6.7	100	6.7	75	7.7	3
Blank	- -	—	6.7	100	7.7	3.5
Irradiated	8.6	100	8.9	85	8.4	7
Blank	- -	—	8.6	100	8.9	3

Discussion of Results

It may be readily observed from the data that color removal is not effected by simple irradiation (i.e. subjecting the water to the action of ultrasonic vibrations). However, there is some slight indication of a possible change in the physical nature of the coloring matter, as evidenced by the fact that some irradiated samples, particularly those of the leaf liquor, were cloudier than, and of a different hue from the original sample, even though the apparent color remained the same. Furthermore, there were a few indications of a small, but perceptible increase in color.

In addition to the data included herein, similar results were obtained in some earlier irradiations of ordinary orange-pekoe tea, diluted to a color of 90 ppm. In these cases also, no color removal could be shown. Believing that a more plentiful supply of oxygen might give results, a stream of air was bubbled through the sample for about twenty minutes preceding the irradiation. Here again however there were no signs of color decrease.

Since both the literature and preliminary tests show that irradiation often results in an acceleration of oxidation reactions, it is conceivable that the coloring matter might be altered in composition, or that other material formerly colorless might take on a definite hue, thus adding to the total color of solution. Any attempt to justify this hypothesis, though, would require a complete chemical analysis of the water and isolation of the

coloring agents, both of which are beyond the scope of this undertaking.

There is a possibility that with particular color problems, such as might occur with very special surface waters or industrial wastes, ultrasonic vibrations may be a valuable asset, but for the waters used, it had no apparent effect.

In the case of colored waters first irradiated and then coagulated, it may be said simply that the action of ultrasonic treatment apparently has no effect, either favorable or unfavorable, on the efficiency of color removal with alum. Whether or not a higher intensity of sonic energy might give more definite indications is open to question.

Irradiation of turbid waters was found to give some indication, at least in the case of the silica suspension, of causing a small but measurable amount of turbidity removal. The same result was not borne out in the study of clay suspensions, although with both the silica and the clay and earlier, with mica flakes, there was some visible coalescing of the smaller microscopic particles into macroscopic size particles which could be seen as the irradiation progressed. (This phenomenon is mentioned in various papers in the literature, and was not unexpected.) At the end of the irradiation period, several of the larger coalesced particles remained at the bottom of the flask, but proof that only a weak bonding existed lay in the fact

that shaking of the flask dispersed them almost completely. In order to establish evidence that the small amount of turbidity removal by ultrasonic irradiation was not a phenomenon due to thermal effects, a 100 cc. sample of the silica suspension was heated to 65°C. (the highest temperature reached during irradiations) for about 20 minutes. The turbidity before and after heating was exactly the same (100 ppm). At frequencies approaching the audible range, much work has been done by several investigators. Results indicate that a study in this lower range of the effects on particles causing turbidity might be profitable.

In the attempt to study the effect of pre-irradiation and coagulation on these samples, it was found so easy to remove practically all turbidity by coagulation alone that no conclusion could be drawn as to the effects of the ultrasonic vibrations. The very minimum dosage of alum required to form the least visible floc was enough to remove so much of the turbidity that any possibility of comparison with the irradiated sample was obviated.

It is regretable that this work could not be supplemented with more on natural waters, but the plain facts of the case are that there are no known turbid waters in the immediate vicinity, and very few colored ones. Moreover, it should be emphasized here that this investigation is only the basic beginning of the many studies that must be conducted along these lines before it can be definitely proven that ultrasonic treatment of waters is or is not of any importance.

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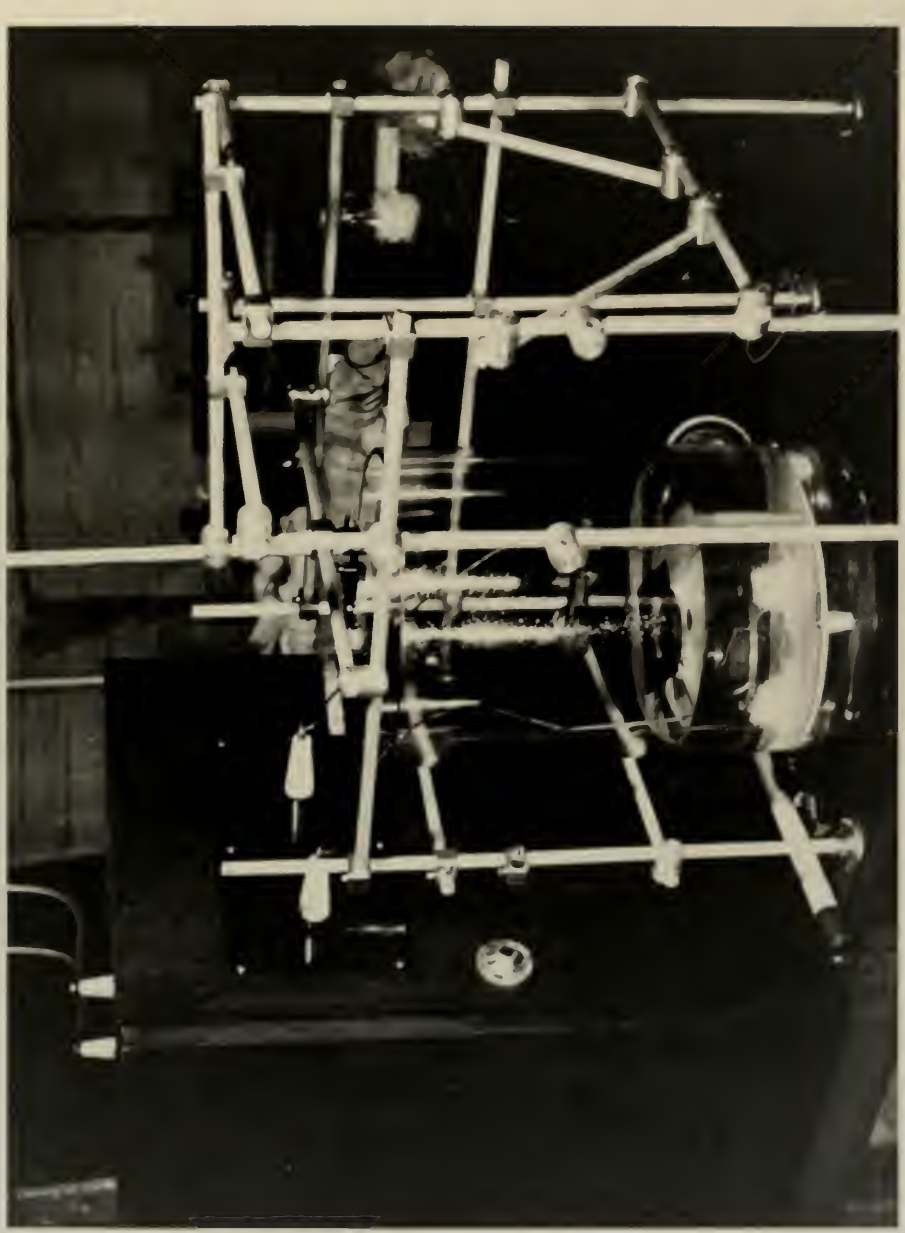

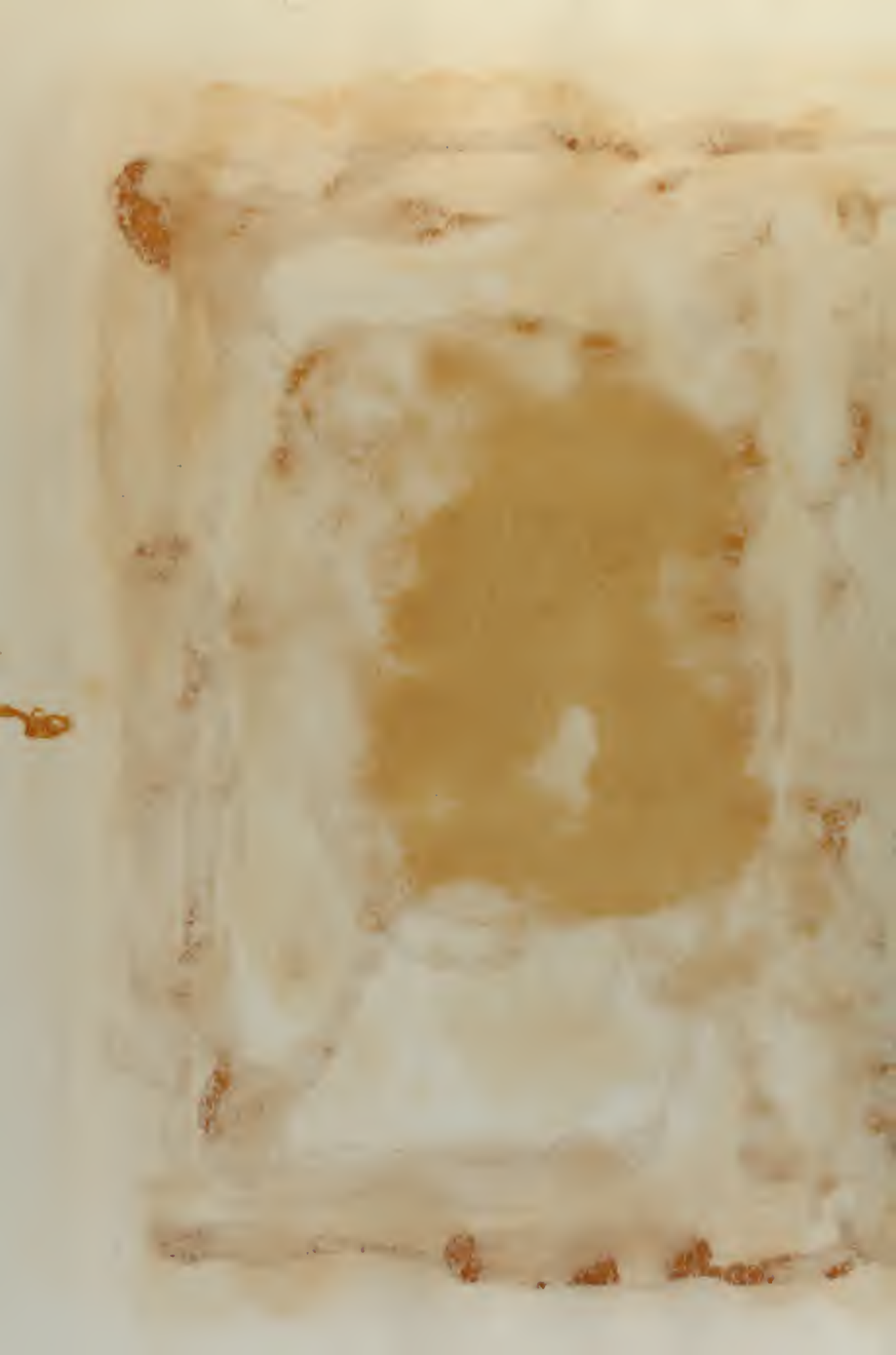

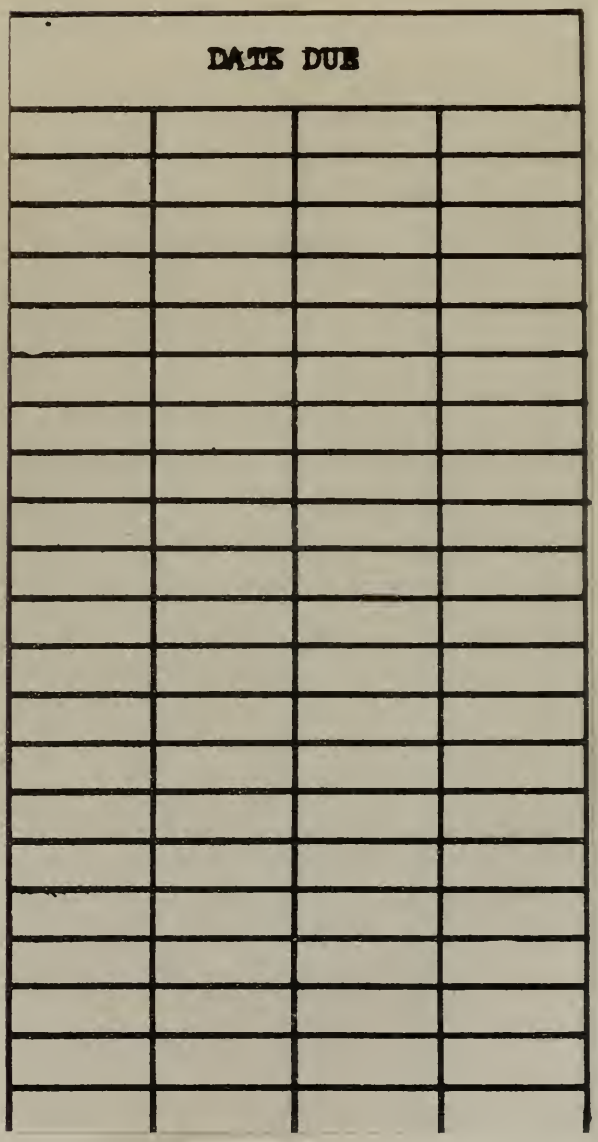
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Study of the effect of ultrasonic vibrations on the color and turbidity of waters.